Issued October 17, 1908.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN 338.

MACADAM ROADS.

BY

AUSTIN B. FLETCHER,

Special Agent, Office of Public Roads.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., July 15, 1908.

Sir: I have the honor to transmit for your approval a manuscript by Mr. Austin B. Fletcher, secretary of the Massachusetts Highway Commission and special agent of this Office, upon the construction of macadam roads. This manuscript gives in some detail the best practice in macadam road construction. The material contained therein has already been published in Bulletin No. 29 of this Office, but the great increase in the demand for reliable information upon the construction of macadam roads makes the publication of a condensed and revised edition of that bulletin for wide distribution advisable. I respectfully recommend, therefore, that this manuscript be published as a Farmers' Bulletin.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

338

MACADAM ROADS.

INTRODUCTION.

This bulletin is intended as a brief description and discussion of the several processes and essential features entering into the construction of macadam roads in rural sections. Some data as to costs, especially for the information of road officials who have not undertaken such work, are included.

The details of construction may require modification to some extent to be suitable for different parts of the country, depending upon rainfall, temperature, and topography, but the general type of road to which this bulletin relates is adaptable to nearly all parts of the United States where suitable stone exists or to which such stone may be carried without excessive cost.

The word "macadam," as herein used, relates to a surfacing composed of stone broken into small fragments, the largest not exceeding 2½ inches in diameter, suitably bound together into a compact mass so as to be substantially a sort of concrete, but with no binder other than stone dust or screenings. A road so surfaced might be more properly called a "broken-stone" road.

The macadam type of road surfacing is particularly well adapted to main highways connecting centers of population, on which there is moderate travel. It is not an economical form of pavement for the main streets of cities and large towns, and it is usually too expensive for country roads other than the main highways. It resembles closely a gravel road. When a road built of gravel is not quite sufficient to resist successfully the wear and tear of the traffic over it, macadam surfacing may usually be substituted for the gravel with satisfactory results. Sometimes a macadam surface may be used with economy when the conditions are such that a gravel surface would satisfy the demands of traffic but good gravel can not be obtained at reasonable cost.

DIMENSIONS OF THE MACADAM SURFACE.

For ordinary country roads, experience has shown that the broken-stone surface need not be more than from 12 to 15 feet wide, if suitable shoulders are built on each side. Twelve feet allows two vehicles

to pass each other safely. Fifteen feet is more satisfactory, particularly when motor vehicles are passing each other. If the stone is less than 12 feet wide, there is a likelihood that the edges of the macadam will be sheared off by wheels unless the shoulders are made of especially good material. Whatever may be the width of the stone, the shoulders should be firm enough to permit the occasional passage of wheels over them.

Until within comparatively recent years it has been almost universally the practice to build thick macadam roads. Roads less than 8 inches thick were rarely heard of, and often a thickness of at least 12 inches of macadam was thought to be necessary for good results. The more recent practice is to make the macadam surface as thin as possible, yet with sufficient body to stay in place, the theory being that the macadam is only a wearing surface. By lessening the thickness of the macadam much expense may be saved, since the foundation materials are usually less costly than broken stone. The macadam should be hard, smooth, and impervious to water. Much attention must be given to the foundation. It should be composed of porous material free from clay or loam, firm, and sufficiently strong to sustain any load likely to come upon the road at any time of the year.

In new work, where no macadam has been laid before, 3 inches of macadam after rolling is the least thickness which is practicable; and, except in unusual cases, a depth greater than 6 inches after rolling is rarely necessary if the foundation is suitable.

The ordinary macadam road is usually from 12 to 16 feet wide, with shoulders 3 to 5 feet in width on each side of the broken stone. The thickness of the macadam is usually 6 inches at the center and 4 inches at the sides, or a uniform depth of 6 inches throughout.

STONE FOR MACADAM ROADS.

KIND AND QUALITY.

The principal qualities which are necessary in road-building stones are hardness and toughness. The cementing values of the stone dust should not be forgotten, but these are not so important as the qualities first mentioned. Often the choice of stone is very limited. It may be that only field stones may be had, or perhaps nothing but inferior ledge stone can be found, except at a prohibitive cost.

Trap rock—meaning by the term the diabases, the diorites, and certain other igneous rocks—has long been considered the best material for macadam purposes. Unfortunately, except in certain localities, these stones are not common. Some of the hornblendic granites give good results, as do the felsites and some of the harder limestones.

The slates, schists, most of the sandstones, the micaceous granites, and the quartzites have but little value as road-surfacing material. Often these stones may be used economically in the lower course of the macadam, provided the upper stratum is composed of a better grade of stone. But road officials should avoid the selection or rejection of stones because of their names alone. Some large-crystalled granites and some of the limestones are of very little value, and, on the other hand, there have been instances where certain schistose rocks have been used with excellent results. Stone from a ledge, because of its uniformity in desirable qualities, is usually better than field stone and makes a smoother and more durable road; but if the ledge is of an inferior grade of rock, it should not be used, merely because it is ledge, in preference to field stones of a better quality of rock.

At the present time there should be no difficulty in determining the relative values of stones for road purposes in any locality. The Office of Public Roads, of the United States Department of Agriculture, now undertakes to make tests and analyses of samples of stones, without charge, and to give advice as to their value for road-building purposes.

THE WEIGHT OF BROKEN STONE.

When broken stone is bought from a manufacturing company and shipped by rail, or otherwise, it is frequently sold by weight. Before estimating the cost of a road when the stone is to be paid for by weight, the road official must know how much the stone will weigh per cubic yard. To dispel the somewhat general impression that all stone weighs the same per unit of volume and that a cubic yard of broken stone always weighs a ton and one-third, the specific gravity and weight of a number of different kinds of rock are given in Table 1. The table is from data recently published by the Office of Public Roads.

TABLE 1.—*Specific gravity and weight of various rocks.*

Number of samples tested.	Name	Specific gravity.			Weight per cubic foot of solid rock.			Weight [a] per cubic yard of solid rock.		
		Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
					Pounds.	*Pounds.*	*Pounds.*	*Tons.*	*Tons.*	*Tons.*
3	Peridotite (trap)	3.55	3.25	3.40	221	203	212	2.984	2.741	2.862
124	Diabase (trap)	3.20	2.60	2.95	200	162	184	2.700	2.187	2.484
33	Diorite (trap)	3.35	2.70	2.85	209	168	178	2.821	2.268	2.403
60	Schist	3.20	2.65	2.90	200	165	181	2.700	2.227	2.443
11	Felsite	2.80	2.50	2.65	175	156	165	2.362	2.106	2.227
53	Quartzite	3.10	2.50	2.70	193	156	168	2.605	2.106	2.268
358	Limestone	3.10	2.00	2.65	193	125	165	2.605	1.687	2.227
106	Granite	3.00	2.00	2.65	187	125	165	2.524	1.687	2.227

[a] Tons of 2,000 pounds.

In Table 1 the weights are of solid rock. If it be assumed that the volume of the stone after it is crushed and as it lies in the bins has

50 per cent of voids, and the average weight of peridotite is compared with the average weight of granite, it will be seen that crushed peridotite weighs 1.43 tons to the cubic yard, while the granite weighs only 1.11 tons. The heaviest diorite weighs 1.41 tons to the cubic yard and the lightest only 1.13 tons. Differences as marked as these will be found in the different stones referred to in the table.

After broken stone has been carried for some distance on the cars or in carts it packs, and a given weight will not occupy so much space as before it began its journey. In contracting for stone by the cubic yard the place of measurement should always be agreed upon in advance.

In Massachusetts the State highways are all built by contract. All of the broken stone used in the macadam work is weighed, so that the weight of the stone in all of the roads is a matter of record. In fact, it might almost be said that the roads there are built by weight rather than by measurement. (See page 22.)

On the roads built in Massachusetts in 1906 the imported stone—in all cases trap rock—covered 3.13 square yards of surface to the ton of 2,000 pounds where it was intended to average 5 inches in depth after rolling.[a] Where a thickness of 4 inches throughout the cross section was employed a ton covered 3.76 square yards. The local stone, which consisted mostly of field stones and was usually some variety of granite and of less weight per unit of volume than the trap, covered in the 5-inch sections 3.32 square yards and in the 4-inch sections 4.03 square yards.

TOOLS AND MACHINERY.

STONE-CRUSHING OUTFITS.

In addition to the shovels, picks, and other ordinary implements, a considerable outlay for machinery is necessary. In these days of high-paid labor and short working hours one rarely hears in this country of macadam stone being broken by hand.

There are many kinds of stone crushers on the market. Except for city use and in cases where a large amount of macadam work is done every year within a comparatively small area, large stationary plants are undesirable. There are several kinds of portable plants which may be bought at prices ranging from $1,600 to $2,500, which are admirably adapted for country use. These plants include the stone crusher, engine and boiler, portable bins, revolving screen, and an elevator to lift the stone after it is broken and to discharge it into the screen.

---

[a] Six inches thick at the center and 4 inches thick at the sides.

The outfits are mounted on wheels and may be moved from place to place at a comparatively small cost. Under ordinary conditions from $50 to $100 will pay the expense of shifting such a plant from its old location to a new one several miles distant.

Stone crushers are variable in their outputs. They all need much repair work from time to time, on account of the severe usage to which they are subjected. With an outfit such as has been mentioned, from 80 to 100 tons (60 to 80 cubic yards) of broken stone per day may be reasonably expected if the plant is kept in good condition. Such an output is usually satisfactory, since a single steam road roller will not often roll more than this amount in a day. The crusher will take stones which measure up to approximately 7 by 14 inches in cross section; larger stones require mauling before they can be placed in the receiving orifice.

In some places it may be found more economical to have the stone shipped in from some permanent crushing plant than to purchase a crushing outfit, and it is well to consider this feature carefully. It should also be stated that while the first cost of the road is important, the costs of future maintenance must also be taken into account. It is sometimes economical, even at a greater initial cost, to import stone from a distance, if thereby a more durable road may be had than is possible by the use of local stone.

In places where the stone supply is limited to ledges at infrequent intervals, there is often but little choice as to the location of the crushing plant. It is as easy to haul the broken stone to the road if the crusher is set up at the ledge as it is to haul the unbroken stone from the ledge to the crusher if set up beside the road. But if field stones are to be used or suitable ledges are available along the road to be constructed the crusher should be located near the road. Experience has shown that 2 miles of road is about the economical limit for operating the plant in one place. If a greater length of road is to be built it is usually cheaper to move the plant than to haul its product a longer distance.

The plant should be set up as nearly as practicable in the center of the section to be built; but since much water is needed for the boiler, for the roller, and for the watering cart, the crusher site is often governed by the location of the water supply.

If possible the crusher should be set low enough so that a platform may be built at the level of the opening which receives the stone. This platform should be sufficiently strong to bear the weight of the carts loaded with stone for the crusher. With this arrangement the large stones may be dumped upon the platform and fed into the crusher without further lifting.

The workmen who set up the plant should have had experience in this work. Much depends on the proper alignment of the several parts, and many petty annoyances in operation will be avoided if the work is done properly in the first instance.

ROLLERS.

The steam road roller is now used to so great an extent that a discussion of its advantages over the horse roller is unnecessary. Macadam roads may, of course, be built with rollers drawn by horses; they may also be built without any rolling except by the wheels of moving vehicles. But experience has demonstrated that quicker and better work can be done with the steam roller, and usually at a less cost. A so-called "10-ton roller" is sufficiently heavy for country roads. Most of the culverts and many of the bridges are too weak to sustain, with safety, the heavier rollers. There are several excellent makes of such rollers, which may be had at prices ranging from $2,500 to $3,500.

WATERING CARTS.

Since water is always needed in rolling the macadam, a watering cart or sprinkler should be provided. The road official can not often afford to wait for rain. A cart with a capacity of 450 to 600 gallons will be sufficient. Most of these carts are provided with extremely broad tires, so that the cart assists in consolidating the stone, instead of rutting it. Many communities are provided with one or more watering carts, so that it is often unnecessary to purchase a new one for road building.

ROAD MACHINES.

Many road officials have a road machine which they can use. This is a most serviceable implement when used properly. Often it is misused in repairing earth roads. The practice of scraping back upon the road worn-out material which has been washed into the gutters can not be too heartily condemned. The road machine can be used to advantage in preparing the road for the broken stone. Drag and wheel scrapers are useful in grading and shaping the roadbed. Automatic spreading carts of several different kinds are often used in spreading the broken stone. They are useful and save considerable time and labor, but are not essential.

LABOR AND TEAMS.

In macadam work, as in all other construction work, there should be a competent foreman or superintendent in charge.

Since no two pieces of road are ever alike, no definite statement can be made as to the number of men required for the grading and

other details, except with regard to the broken-stone portion of the work, and the same is true with regard to teams. The foreman has an opportunity to use considerable judgment and skill in arranging his men and teams so as to secure a maximum of effect with a minimum of effort.

Not many laborers are required to take care of the output of a single crushing plant. The crusher engineer and the roller operator should be skilled mechanics. Both of these men act as firemen, and, in fact, usually take entire care of the machinery under their charge. Two ordinary laborers are usually enough to feed the crusher, with a third man to assist them occasionally and to maul stones which are too large for the receiving orifice. Two spreaders are needed to take care of the broken stone as it is delivered on the road, and a driver and a pair of horses are required for the watering cart. It is impossible to give the number of teams needed for the broken stone, since the number is dependent almost wholly on the length of haul.

To show how the number may be ascertained in a specific case, the following example is given: Assuming that the average length of haul from the crusher to the point of delivery on the road under construction is 1 mile; that the route of haul offers no unusual difficulty in grade or surface; that 100 tons (about 80 cubic yards) of broken stone per day is to be hauled to the road; and that 2 tons are to be carried in each 2-horse load; then one team to do the work would have to make 50 trips of 2 miles each, or, in other words, it would have to travel 100 miles per day. Since a pair of horses engaged in this kind of work will not average more than 20 miles a day for many consecutive days, under the conditions assumed, five teams would be necessary.

If the crusher is set up at a ledge there will be no teaming to it, but if field stones are to be crushed, the hauling of these stones to the crusher must be considered also, unless, as frequently happens, farmers haul the stones from their own land and deliver them at the crusher at prices agreed upon.

In quarrying ledge stone, the number of laborers depends largely on the character of the stone, and each case must be considered by itself.

EARTHWORK.

A civil engineer should lay out the work, establish the grades, and set the grade stakes. Often in rebuilding an existing road it is advisable to change the grades to a considerable extent, and then the services of a civil engineer are likewise required.

Theoretically, the grades should be as nearly level as possible, but in most localities this ideal condition can not be realized, nor will the

available appropriation usually permit even an approach to the maximum grades adopted by the railroads. Practically, in road construction little is ordinarily done beyond reducing the hills to the maximum grade which has been adopted and in removing the irregularities between the hills. If suitable, the materials excavated from the hills are used in filling the depressions.

It is obvious that the subgrade or foundation is the part of the road most nearly permanent. No matter what surfacing material is used, it will eventually wear out and require renewal. The grades, therefore, should be most carefully studied, since after the macadam surface is completed they can not be changed without great expense.

In American practice the maximum grade for important roads has been generally fixed at 5 per cent where such a grade can be had without too great expense for grading and for damage to abutting property. By 5 per cent is meant a vertical rise of 5 feet in 100 feet of horizontal distance. A horse can trot without especial difficulty up such a grade. On steeper grades, macadam surfaces, or, indeed, any kind of a surface, can be maintained only at considerable cost.

Some authorities insist that a macadam road should never be level, arguing that a slight rise and fall is needed to permit the surface water to run longitudinally along the road. Usually, even if the road is absolutely level, if it is also properly crowned, the gutters of the road may be so graded as to provide suitably for surface drainage. The width of the grading will depend, of course, on the width of the macadam adopted.

In fixing the grades care must be taken to adjust the cuts and fills so that there will be little or no waste of material. This requires some judgment and experience, since most materials shrink to a greater or less extent when taken from the cuts and placed in the fills. It is estimated that this shrinkage, together with certain unavoidable waste, averages about 15 per cent. When the depth of the fill is but a few inches, the use of the steam roller will often cause a much greater shrinkage.

A line of grade stakes should be set on each side of the roadway. These stakes should be not more than 50 feet apart and the established grade should be plainly marked on them. They should be set sufficiently far from the roadway not to be disturbed by the grading and other operations. These stakes will serve later for the macadam work.

The road should be graded to the approximate subgrade elevation, with a sufficient surplus of material to form the shoulders. It should also be remembered that the materials will settle to a considerable extent when the steam roller is brought on.

The surface water should always have opportunity to drain from the roadway as quickly as possible, and the gutter grades should be

so fixed that there will be at least 6 inches fall in 100 feet. With a less fall, if there be snow in the winter, the water will be held back and cause trouble. Deep ditches beside the road are dangerous to travelers and are usually unnecessary. It is a better practice to construct culverts more frequently and to lay pipes longitudinally under the road connected with catch basins and leading to suitable outlets.

No impervious materials, such as clay and loam, should be permitted within at least 18 inches of the top of the completed road, particularly if it is in a locality where the ground freezes in winter. All stumps and roots should be grubbed out and removed. The clay and loam may be placed on the sides of the road, but such materials should not be permitted under the broken stone. Sand, gravel, or other material which does not hold water should replace them.

DRAINAGE.

SUBSURFACE DRAINAGE.

Water should never be permitted to remain under a macadam road. It softens the foundation so that the broken stone is forced down into it by the wheels of vehicles, thus causing ruts to develop in the macadam. In freezing it expands and "heaves" the broken stone, destroying the bond and causing the larger fragments of stone to rise to the surface. As a result the material in the subgrade is forced up into the interstices, and in the spring the macadam will be found to be rough, irregular in shape, and weakened. There are several ways of removing the subsurface water, at least in part. Sometimes if the grade is raised in wet places the trouble will be lessened, particularly if porous materials are used.

Side Drains.

Side drains may be constructed in the cuts on each side of the road, just outside of the limits of the macadam. (See fig. 1, bottom.) These drains consist of narrow trenches, filled with broken stone or small gravel stones, with a pipe 5 or 6 inches in diameter near the bottom. The pipe is laid with open joints, true to grade, and is carried to a proper outlet. Sometimes the pipe is omitted and the entire trench is filled with stones, in which case it is called a blind drain. Such drains serve to cut off the subsurface water before it can get under the macadam.

V Drains.

The subgrade may be excavated to the width of the macadam so as to be 6 to 8 inches deep at the edges, and 12 to 18 inches deep at the center. The surface will then have the shape of an extremely flat-

tened letter V. (See fig. 1, middle.) The bottom should be fairly true to grade, so as to permit the water to flow readily. This excavation is filled with stones varying in size from small pebbles to boulders 8 or 10 inches in diameter, the largest being placed at the bottom. These stones need not be placed with special care, but the condition of the mass should be such as to permit consolidation with a roller. To dispose of the water collected by a drain of this kind, narrow trenches should be cut to the sides so as to connect with open outlets. These trenches should also be filled with stones. Such a drain is usually effective and ordinarily costs less than two side drains.

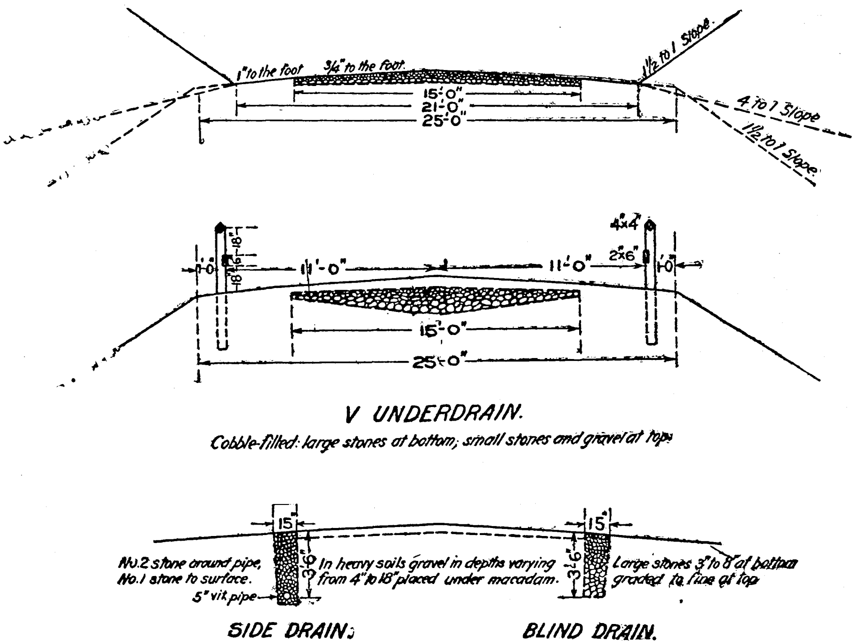

FIG. 1.—Typical cross sections of macadam roads.

Telford Foundations.

Another way of nullifying in part the effect of the subsurface water is to construct a foundation of telford. Formerly, nearly all macadam roads were built with a telford base, regardless of any consideration of the requirements of traffic. It is now generally recognized that, except in unusual cases where the subsoil is full of water which can not be drained out, the telford base is unnecessary except for purposes of subdrainage. A satisfactory telford foundation may be made by placing vertically on a layer of gravel 2 or more inches in depth, stones of fairly uniform size, not exceeding 10 inches in width, 6 inches in depth, and varying in length from 6 to 20 inches. The

stones should be set on their broadest edges, lengthwise across the road, and wedged rigidly into position by driving smaller stones into the interstices with mauls. Projecting points should be broken off with stone hammers, depressions filled with chips, and the telford rolled with a steam roller until it is true to the desired cross section.

Where the foundation of the road would otherwise be very bad, and no gravel or other like material is readily obtainable, or where an unusually substantial road is required to meet the demands of traffic, this form of construction is recommended. Under ordinary conditions it is much too expensive. It has been said, and there is some supporting evidence, that a rigid and unyielding telford base has the effect of an anvil, and that the macadam, under the pound of traffic, wears more rapidly than in the ordinary broken-stone road.

Several other devices are sometimes employed to take care of the subsurface water, such as the center box drain, built of slabs of stone, and side drains, with plank boxes in lieu of drain tile. Usually these are either too expensive or of too unstable a nature to be recommended.

SURFACE DRAINAGE.

The removal of surface water has already been discussed to some extent under the subject of "earthwork" (pp. 12, 13).

It is obvious that the water which falls on the road and which flows upon it from adjacent lands should be got rid of as soon as possible. Culverts should be built at low points where outlets are available, and existing streams should always be utilized for outlets. The water should never be carried in the gutters or in side ditches any farther than is necessary. When the volume of water is small, it may often be carried across the road in tile pipes buried sufficiently deep not to be broken by vehicles upon the road. If it is necessary to lay a pipe within 2 feet of the surface of the roadway, iron water pipe or gas pipe should be used. For larger volumes of water culverts of rubble masonry or Portland-cement concrete may be built. Very often it will be found to be more economical to use the concrete, particularly if it is reinforced with steel.

Large culverts and bridges should always be designed by competent civil engineers and constructed under their supervision. Indeed, very often the advice of such an engineer in regard to the smaller waterways might be sought with profit. Money is too often wasted from a lack of knowledge concerning the proper sizes of pipes and culverts.

In many localities it is the custom to have the main road and driveways from adjacent lands intersect at the same center grade. This practice makes it necessary to carry the gutter water under the driveway in a pipe. Nearly always it is possible, by regrading

such a driveway, to make it coincide with the gutter grade, so that the surface water will flow by without interruption. This should always be done when possible. Pipes with open ends laid at the gutter grade are always unsatisfactory, since they fill up quickly with leaves and sand and with slush in winter time, and thus the surface water is forced out upon the macadam and soon gullies it. When a pipe is required, a catch basin should be built on the upper side of the driveway, the pipe should be laid to connect with it, and carried sufficiently far underground to discharge properly into the gutter below the driveway.

In cuts where the grade is in excess of 3 per cent and where the soil is loose or sandy it is sometimes necessary to pave the gutters with cobblestones or with paving bricks or paving blocks to prevent the formation of gullies in the shoulders and in the macadam. Usually a gutter 3 feet in width laid on the same or a little greater slope than the macadam, with an outer row of large stones about 1 foot high laid vertically against the bank of the cut, is sufficient. Such a gutter usually replaces the shoulder, and it should not be constructed until after the macadam is substantially completed.

SHAPING THE SUBGRADE.

It is not enough that the roadway shall be graded with reasonable care. The surface upon which the broken stone is to be placed must be hard, smooth, and carefully crowned. If the foundation is not hard and firm the stones will be pressed into it by the roller and wasted. If not crowned, an unnecessary quantity of stone will be used. When the macadam is to be of uniform thickness throughout its cross section, the crown of the subgrade should be the same as that of the finished road. If the macadam is to be thicker at the center than at the sides, a part of the crown will be in the macadam itself and the center of the subgrade should be raised enough to produce the contemplated surface crown when the stone is in place. In shaping the subgrade, a road machine can generally be used to advantage.

Usually sufficient material is left on the sides to form the shoulders for the macadam. If the natural soil is not sufficiently good for shoulders, suitable material should be brought on at this time. The shoulders, in addition to affording a surface for the occasional passage of wheels, serve to some extent to prevent crowding the broken stone outside the limits of the proposed macadam roadway during the rolling.

After the roadbed is shaped to the approximate cross section it should be rolled thoroughly until it is hard, firm, and smooth. This is essential, since if the subgrade is soft much of the broken stone will become embedded in it later. If soft places are found or depressions develop during the rolling, more good material should be put on,

so that when the subgrade is ready for the broken stone it shall conform to the proposed cross section as nearly as practicable.

THE COURSES OF MACADAM.

SIZES OF STONE.

All modern crushing plants are equipped with revolving screens to separate the broken stone into sizes, and after passing through the holes of the screen the stones fall into their appropriate bins. The "tailings," or stones which are too large to pass through the holes in the screen, run out at the lower end upon a conveyor, which carries them back to the mouth of the crusher to be broken again.

Usually there are three sections in the screen; the first, nearest the higher end, has holes sufficiently large to allow fragments not exceeding one-half inch in diameter to pass through. The holes in the second section permit stones 1¼ inches in diameter to pass through, and those in the third section allow stones 2½ inches in diameter to pass through. All larger stones are forced out at the open end of the screen, where they drop upon the "tailings" conveyor.

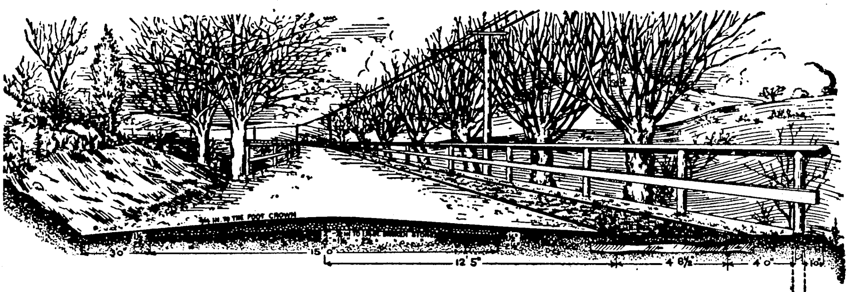

FIG. 2.—Standard road section (Massachusetts Highway Commission.)

A stone 2½ inches in diameter is as large as should be used in macadam work. Usually fragments of this size are used in the lower or first course. Those of the 1¼-inch size are used in the upper course. If the stone is hard, this size is about as large as can be used to give a smooth surface. Soft stone will often crush under the roller, and, where such stone is used, sizes larger than 1¼ inches may sometimes be used with good results.

The jaws of the crusher should be set so as to make as few "tailings" as possible, and the lengths of the screen sections should also be properly adjusted to the same purpose.

CROWN.

Every macadam road should be crowned, in order that the water falling upon it may run quickly to the gutters. It is also necessary that the shoulders should have the same slope as the macadam or perhaps a little greater. (See fig. 2.)

For a road 15 feet or less in width it will be found satisfactory to have the center 5½ inches higher than the sides, forming a crown of three-quarters of an inch to the foot. On roads of greater width it will be necessary to reduce the crown to one-half inch to the foot, or perhaps even less. The apex should be slightly rounded.

THICKNESS OF COURSES.

Since the wear at the center of the roadway is always greater than at the sides, some saving in stone may be made by reducing the thickness at the outer edges. A layer of loose stones more than 6 inches deep can not be compacted with a roller easily, if at all, and modern roads are all built in two or more layers or courses.

To secure smoothness and even wearing, the smaller sizes of stone should be placed in the upper course and the larger in the lower. When a road is built with the sizes mixed, unless the stone is unusually soft, a rough surface inevitably results in a comparatively short time after the road is opened to travel.

When broken stone is spread loosely, as on a roadway before it is rolled, the voids aggregate between 40 and 50 per cent of the volume of the layer or course. The roller passing back and forth over the course consolidates the material and a large percentage of the voids, often from 30 to 40 per cent, is eliminated. To secure a finished roadway 6 inches thick, about 8½ inches of loose stone, not reckoning the binder, is necessary. This is in part due to the unavoidable forcing of the stones, to a slight extent, into the foundation.

In the State road work in Massachusetts it is recognized that a uniform depth of stone on the roads throughout the State is undesirable, because of differences in local conditions. Table 2 shows the courses and total thickness of stone most commonly applied in that State. The last two are rarely used except in resurfacing a worn-out macadam road.

TABLE 2.—*Thickness of courses of macadam.*

Lower course.		Upper course.		Total thickness.	
Center.	Sides.	Center.	Sides.	Center.	Sides.
Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
4	2½	2	1½	6	4
2½	2½	1½	1½	4	4
4	(a)	2	1½	6	2½
2½	(a)	1½	1½	4	2½

[a] The stone is spread as thinly as possible.

The binder or "matrix," as it is sometimes called, consisting of the stone dust and small fragments of stone which pass through the ½-inch holes in the screen, is not counted as a course. No more of the

binder should be used than is necessary to fill the voids and just cover the upper course of stone.

In Massachusetts no stone dust is applied until after the two courses of stone are rolled thoroughly. Then a thin layer of the screenings is spread, the watering cart is brought on, and the "fines" are flushed down into the interstices. It is rarely necessary to use, altogether, more than 1 inch in depth of the screenings. This method has been followed for a dozen years with complete success.

Under ordinary conditions, no clay, loam, or other like material is needed, either in the interstices or on the surface, to keep the road from "raveling." In very dry and hot climates, and where the roads are subjected to the ravages of motor vehicles operated at excessive speed, it may be necessary to apply some special binder and dust preventive, such as tar or asphalt oil, and for such places these materials are recommended in place of the clay and loam sometimes used and called "packing."

Sometimes binder, consisting of stone dust, sand, and even clay or loam, is worked into the first course during the rolling of that course. It is difficult to see how this practice adds in any way to the integrity of the road. It is true that considerable rolling is saved by this method, and, also, that once in a while, when it is not possible to secure a firm foundation or when extremely hard stone is used, some binder may be needed to keep the lower course in place so that it may be rolled. The use of clay should always be avoided.

PLACING THE BROKEN STONE.

As soon as the drainage work is completed and the roadway has been graded, shaped, and rolled for a few hundred feet, the spreading of the broken stone should be commenced.

Lower Course.

As stated before, the larger sizes of stone, ranging in diameter from 1¼ to 2½ inches, should be spread first. The stone should never be dumped from the carts directly upon the road. When broken stone or gravel is dumped from the ordinary cart it falls in a pile with the smaller fragments consolidated to a greater or less extent in the center of the heap. When the pile is leveled subsequently the core remains almost intact. An uneven road usually results, and often the individual loads may be counted after the road has been in use for some time. Unless automatic spreading wagons are used, the stone should be shoveled from the carts or dumped on a movable platform of planks about 6 feet long and 3 feet wide, sometimes called a "dumping board." The spreaders should then shovel the

stone from this platform upon the prepared subgrade to the required depth for the lower course, remembering, as before stated, that the course will shrink in depth approximately 35 per cent under the roller. The depth of the course should be tested frequently by strings stretched across between the stakes. Sometimes blocks of wood of the required height are set on the subgrade and the stone is spread until the top of the course is flush with the tops of the blocks. The stone is frequently leveled with rakes.

When a hundred feet or so of the first course has been spread, the rolling should begin. It will be found best to begin the rolling at the outer edge of the macadam, running upon the shoulder a few inches. When this portion of the stone ceases to wave and seems firm under the foot, the roller should be moved to the other side of the roadway and the operation repeated there. After both sides of the roadway are moderately firm, the roller should be moved gradually toward the center until the entire lower course is thoroughly compacted.

Sometimes it is found that the wavy motion continues and that the stones will not compact. This may be due to a wet subgrade, which, if allowed a day or two to dry out, will give no further trouble, or it may be due to the use of an excessively hard stone, in which case the application of a little sand or fine gravel may remedy the difficulty. With some soft, coarse, gravel stones, a "crawling" motion may be noticed. In this event, instead of compacting, the sharp corners of the stones become rounded. If the rolling is continued, the stones become like marbles. A slight sprinkling of coarse sand, stone screenings, or, in some instances, the application of water, may prevent this action. It must not be expected that the lower course will be absolutely rigid. If it is rolled enough to prevent the stones from shaking when one walks over them it is sufficient.

If depressions develop as a result of the rolling, additional stone of the same size as used in the course should be added and rolled, and before the second course is put on the lower course should be smooth and true to the cross section.

Upper Course.

After about 100 feet of the first course of stone is rolled, the second course, consisting of the fragments varying in diameter between one-half inch and $1\frac{1}{4}$ inches should be spread from the dumping board and rolled in the same manner as was the lower course. After this course is thoroughly compacted, the binder should be spread. Usually but little more than 1 inch in depth of the screenings is required in 6-inch work. The watering cart should then be put on in advance of the roller and as much as possible of the dust

should be flushed into the crevices between the stones. The roadway should be wet and rolled until it "puddles" on the surface, showing that the voids are substantially filled.

No more of the screenings should be used than is necessary to fill the voids and to leave a very thin covering over the larger stones. Depressions in the upper course should not be filled with screenings, but rather with stone of the size used in that course.

The ability of the roller operator is a very important factor in macadam work. The appearance of the road surface depends to a great extent on his skill.

No matter how much the macadam may be rolled, it will not acquire the metallic ring usually noticeable in roads of this kind for some days. The calks of the horses' shoes will roughen the surface for a short time, and it is a good plan to keep the roller on the completed road moving back and forth during the progress of the work whenever it is possible.

It is well not to allow the lower course to be spread too far in advance of the upper, and to put on the screenings and water and roll them as soon as possible after the upper course is rolled. There is of necessity more or less teaming over the road during its construction, and while the courses are in an uncompacted condition the horses' hoofs and the wheels of vehicles are detrimental to the work; but when the macadam is completed the sooner it is used the better.

THE ROADSIDES.

No matter how smooth and well constructed the traveled road may be, if the roadsides are not cared for, the highway as a whole will not give a good impression. All rubbish should be removed; the excavations should be filled and embankments smoothed and planted with grass wherever it will grow. Unsightly brush should be cut and grubbed out. Sometimes, however, the brush and small trees, if suitably trimmed, add to the attractiveness of the roadside.

All trees that are ornamental or which have value as shade trees should be preserved and protected, unless they grow so close together as to make a dense shade. In hot, dry climates particularly, and, indeed, in most places, trees are a considerable factor in reducing the cost of maintenance, since they lessen the evaporation of the moisture from the macadam. In exposed places where the sweep of the wind would be otherwise unbroken they serve to prevent in a measure the blowing away of the binder from the road surface. Unfortunately in such places it is often difficult to make trees grow. Care in the selection of the kinds of trees best suited to the locality is important.

In Massachusetts, sugar, Norway, and white maples and American elms have been set out to a considerable extent along the State roads with satisfactory results. These trees grow fast and at the same time are fairly long-lived.

A good arrangement along roadsides for trees with large tops is to set them about 50 feet apart on each side, but alternating so that there will be a tree every 25 feet along the road.

THE COST OF MACADAM SURFACES.

Comparison of average costs of roads in one locality with those in another is of little value, for the reason that the conditions in two localities are never precisely similar, and but rarely even approximately alike. Particularly is this true of such details as earthwork and drainage. Even the costs of broken-stone surfacing often lead to wrong conclusions. There are too many factors which are dependent on local conditions. With this caution, certain cost data of macadam work alone are given in Tables 3 and 4. The data are from records of State work in Massachusetts and New Jersey. In each case the measurements and costs are of the stone in place and rolled, and the lengths and costs are estimated upon the basis of a roadway 15 feet in width. They relate to the macadam work alone and do not include the expenses of grading, drainage, or any other incidental items.

TABLE 3.—*Average costs of macadam work in Massachusetts in 1906.*

Source.	Depth of stone at center.	Depth of stone at sides.	Length of road built.	Cost per mile.	Cost per square yard.	Cost of stone per ton (2,000 pounds).
	Inches.	*Inches.*	*Miles.*	*Dollars.*	*Dollars.*	*Dollars.*
Imported stone (trap rock)	6	4	8.25	5,496	0.6245	1.956
	4	4	6.97	4,746	.5393	2.025
Local stone	6	4	21.74	3,696	.4201	1.396
	4	4	6.56	3,459	.3931	1.583

TABLE 4.—*Average costs of macadam work in New Jersey in 1905.*[a]

Depth of stone.	Length of road built.	Cost per mile.	Cost per square yard.
Inches.	*Miles.*	*Dollars.*	*Dollars.*
4	6.441	2,148	0.2422
5	1.772	3,652	.4150
6	7.129	5,637	.6299
8	21.748	6,187	.6958

[a] Report of the commissioner of public roads of New Jersey for 1905.

Further details of the cost of both Massachusetts and New Jersey work are given on pages 33 to 36.

In New Jersey the work appears to be done at a somewhat less cost than in Massachusetts. This may be due in part to the fact that

longer stretches are built in one section in New Jersey. Possibly the per diem rates of pay for labor are smaller there and the hours of labor not so restricted. Road officials in that State are advised to use 2,461 tons of broken stone, exclusive of the screenings, to the mile of road 15 feet wide and 6 inches in thickness after thorough rolling.[a] The screenings needed are estimated to weigh 407 tons to the mile, making a total weight of 2,868 tons. Trap rock is used almost exclusively in New Jersey. In Massachusetts in 1906 the 6-inch-4-inch roads (average depth, 5 inches), built of trap rock and 15 feet wide, averaged 2,810 tons to the mile, including the screenings. It would appear from these figures that in Massachusetts nearly as much stone is used in building the 5-inch roads as is required in New Jersey for 6-inch work.

In Massachusetts, as previously stated, all the roads are built by contract. In some few instances the towns contract with the State board to do the work. In most cases the work is let to the lowest bidder, after advertisement and public opening of bids. In all cases the contracts are made on the unit basis—i. e., the contractor is paid a price agreed upon for each cubic yard of earth moved, for each cubic yard of ledge excavated, for each ton of broken stone laid in place in the road, etc. This method naturally entails much measuring of volumes by the engineers and considerable expense, but it lessens the speculative risk taken by the contractors in bidding on the work, allowing them to make their bids on the lowest basis. The practice surely has the merit of being eminently fair to both parties to the contract. Unless the broken stone is shipped to the work by rail, scales are set up by the contractor near the road, and all stone going upon the road is weighed. The contractor pays for the scales, the State for the weigher. The contractor has no incentive to skimp his work, since he knows in advance that he will be paid for all of the work which he does and for all of the materials which he supplies.

For several years past no actual cost data have been kept of the Massachusetts roads, except in some few special cases. A mass of such records was secured in the early work of the highway commission, and, using the old records, it is possible, without essential error, to analyze the present costs of macadam work.

Two cases will be considered, namely, the average cost of surfacing with imported stone and the average cost with local stone, the consolidated macadam being in both cases 6 inches deep in the center and 4 inches at the sides, or an average of 5 inches. In this analysis of costs of broken stone in place, the macadam surface only is considered. The figures do not include any of the expenses of grading, draining, or other incidental work. In 1906 the cost to the State of

[a] Report of the commissioner of public roads of New Jersey, 1905, pp. 161–162.

the imported stone in place averaged $1.96 per ton. It is fair to assume that the contractor's profit was 15 per cent, on the average, and deducting this, $1.70 is left as the probable actual cost of the stone in place. This is made up, approximately, as shown in Table 5.

TABLE 5.—*Actual cost of imported stone in place.*

Item of cost.	Per ton.	Per square yard of completed road.
Cost of stone on railroad siding nearest the road	$1.15	$0.368
Unloading stone from cars	.07	.022
Hauling from cars to road	.25	.080
Spreading stone	.05	.016
Watering stone	.06	.019
Rolling stone	.12	.038
Total	1.70	.543

The local stone in place cost the State, on the average, $1.40 per ton. Assuming the same average profit to the contractors as before, the actual cost of the work was $1.22 per ton. This is made up, substantially, as shown in Table 6.

TABLE 6.—*Actual cost of local stone in place.*

Item of cost.	Per ton.	Per square yard of completed road.
Cost of stone at crusher	$0.50	$0.151
Breaking stone	.25	.075
Hauling stone to the road	.25	.075
Spreading stone	.05	.015
Watering stone	.05	.015
Rolling stone	.12	.036
Total	1.22	.367

In considering the Massachusetts costs it should be borne in mind that labor there is high and that the hours of labor per day are short. The nine-hour labor law applied to most of the work discussed above, and during the latter part of the year 1906 the eight-hour law was in effect.

Following is a schedule of the average wages per day of the laborers, workmen, and mechanics which prevailed in the year 1906, together with the prices paid for teams:

Ordinary labor	$1.75 to $2.00
Crusher and roller engineers	3.00 to 3.50
Foreman	3.00 to 5.00
One-horse wagon, including driver	3.00 to 4.00
Two-horse wagon, including driver	4.50 to 5.50

In public works some of the elements entering into the actual costs are not usually considered. At least they are usually not included in the costs as reported. The salary of the road official who directs

the work is usually omitted. Some other items are the interest charges on the capital invested in machinery, teams, tools, etc., the costs of repair of such appliances, and the provision for renewing the same when worn out and no longer useful, sometimes called the amortization costs. It is fair to assume that the private contractors, or most of them, take these items into consideration in bidding on the work.

Enough has been stated in the foregoing to indicate that macadam roads when properly built cost a considerable sum per mile, particularly when it is remembered that the cost of grading, drainage, etc., has not been more than referred to in the discussion.

MAINTENANCE.

Someone has said that the maintenance of a macadam road should begin on the day the road is completed. In a sense this statement is not far from the truth. It is usually not necessary to do much to the macadam surface for a year or two; but the gutters, catch basins, and culverts must be kept clean, the weeds along the roadsides must be cut or, preferably, pulled out by the roots, and the small gullies in the shoulders and on the slopes filled before they become too large.

It is quite possible, particularly if the road was built in the fall of the year and trap rock was used, that loose stones will appear on the surface the first spring after the road is opened to travel. These need not alarm the road official. They should be picked up and stacked for future use. It is astonishing how a few loose stones on the surface of a macadam road will have the appearance of a great number, so that the uninformed always think, and frequently say, that the road is going to pieces. It is a fact that often such stones will disappear into the macadam after the first rain.

Of course the macadam will become worn in time and need repair. No one can state accurately how much of the macadam surface will wear off in a given time. The dictum, heard so often, that the macadam will wear down one-half inch in a year's use is a fallacy. The length of life of a properly built macadam road depends especially upon the volume and kind of traffic over it, the quality of the stone of which it is composed, and its peculiar fitness to resist the wear to which it is subjected; also upon the climatic conditions of the locality.

A certain Massachusetts road, built in the best manner of an excellent quality of trap rock, needed resurfacing within two years after it was completed. The road was a portion of a main thoroughfare just outside of one of the largest cities in the State. In addition to the usual heavy traffic to which such a road must be subjected, it was used constantly by drays loaded with the products of several

mills. On the other hand, there are many miles of State roads in Massachusetts built of broken field stones and in use for ten or twelve years on which little or no surface repairs have been needed. In the first case mentioned it was probably a mistake to have used the macadam type of surfacing. Vitrified paving brick, or possibly blocks of granite or some other hard material, would have better suited the conditions. In the latter case the field stones have served their purpose admirably, though some of the roads could and probably would have been built of gravel had that material been obtainable at a reasonable cost.

It was formerly held that the macadam surface should be restored annually to its original thickness. Doubtless this practice was excellent, so far as the condition of the roads was concerned, but such annual restoration is costly. The present practice is to keep the surface always smooth, to fill any small holes or incipient ruts which may appear, but to do no resurfacing until the stones have worn down at least to the lower stratum of the macadam. Too often the resurfacing is delayed longer than economical considerations will justify.

By the time the upper course has been worn through, the road is usually more or less out of shape. As before stated, most of the wear is near the middle of the road. The sides tend to build up as the center wears down. When the road is in this condition it should be resurfaced with the best stone which is available. It should not be necessary to put on more than 3 inches in the center and the stone at the sides may be spread as thinly as is possible. Usually the road surface is " spiked up " with the picks in the wheels of the steam roller. There are several so-called " scarifiers " on the market, which are sometimes used, but they are seldom needed on country roads. Sometimes no " spiking " is needed if 3 inches or more of stone is put on, since this depth will usually give a sufficient body to hold together.

Such resurfacings are usually relatively inexpensive. There is no trouble with the foundation and the stones settle quickly into place and stay there. When the resurfacing is completed the road is as good as new. It has been stated that such work should be done in Massachusetts at not exceeding 10 cents per square yard for each inch in depth of new surfacing material rolled in place. This is a liberal estimate for most work of this kind.

In Massachusetts, where the highway commission not only directs the original construction of the roads but their maintenance as well, it is necessary to keep account of the repair costs accurately, since the counties and municipalities, respectively, are assessed annually for certain percentages of the expenses. The State roads there, at least 95 per cent of which are of the macadam type, have averaged, for ordinary maintenance, approximately $100 per mile per year. These roads, almost all of which are 15 feet wide in the macadamized

portion, have been in service for one to thirteen years. A few sections now require resurfacing and each year some of this work is done. Only a relatively small part of the resurfacing cost is included in the annual cost per mile above stated, but it is believed that an expenditure of not exceeding $200 per mile per year should be the maximum amount necessary to provide for both ordinary and extraordinary repairs.

At the present time the worst foe of the macadam road is, perhaps, the motor vehicle. The steel wheels of the ordinary vehicle grind off sufficient powder from the stones to serve as a binder, replacing the binding material blown away by winds or washed off by rains. It is usually possible, when the binder becomes deficient and the stones in the upper course begin to appear, to spread a little coarse sand in the center of the macadam road. The sand is soon spread by traffic over the greater portion of the width of the macadam. It relieves the roughness and keeps the stone from raveling. This practice has been followed in many sections for years. But the swiftly moving motor car of the present day has introduced a new problem into road maintenance. The large rubber tires on wheels of small diameter appear to exert a suction on the binder of the road. The vehicle moving rapidly over the road lifts the dust into the air in clouds, and it is blown away into the fields.

Various substances are now being applied to road surfaces to lessen or obviate this evil. Coal tar and oils with an asphaltic base seem to give the best results. In France tar has been used for several years, it is said, most satisfactorily. It may be that by some such application not only will the roads be saved from denudation by motor vehicles, but the costs of ordinary surface repairs will be lessened as well.

A properly built macadam road in the country rarely becomes muddy except from mud tracked upon it from side roads built of earth. That they are often dusty can not be denied. Watering or sprinkling is a luxury that can not often be afforded on country roads. When properly applied, water not only lessens the dust nuisance, but preserves the road as well.

No one with experience in such matters will contend that a macadam road may generally be maintained at a less cost than a gravel or an earth road. Sometimes under certain conditions its cost of maintenance may be less, but not usually. But it is true that a macadam road, such as is recommended in this bulletin, may at a moderate expense be kept smooth, hard, and serviceable at all times of the year and that these requirements can not be met by either the earth or the gravel road.

A series of drawings of standard details of Massachusetts roads (figs. 3–10) will be found on pages 36 to 39.

APPENDIX.

MASSACHUSETTS SPECIFICATIONS.

The following are excerpts from specifications used in the construction of State-aid roads in Massachusetts:

Earthwork.

The roadbed shall be graded for the width of ——— true to the lines and grades given by the engineer and in conformity with the plans, profiles, and cross sections furnished by the commissioners, and so shaped that after the broken stone is rolled in place the surface of the roadway shall have a crown of three-quarters of an inch to the foot.

All clay and spongy material shall be removed to a depth to be determined by the engineer, and the space thus made shall be filled with such material as the engineer may direct.

In general, embankments will be made from material from within the location of the road, as will also all filling and grading, but if there is not sufficient suitable material in the excavation, in the opinion of the engineer, the contractor shall find such material outside of the highway location. Such material will be classed as borrow.

Embankments shall be formed of successive layers of not more than twelve (12) inches in thickness, each layer to be thoroughly rolled by a roller weighing not less than two tons.

All trees, stumps, and roots within the roadbed and on slopes shall be grubbed up and removed as the engineer may direct, without additional compensation.

Ditches of such width and depth as the engineer may direct shall be excavated by the contractor wherever the engineer may order them, at the contract price for excavation.

All surfaces in slopes or on embankments, whether old or new, shall be left with neat and even surfaces according to the lines, grades, and directions given by the engineer, without additional compensation.

All measurements of earthwork shall be made in excavation.

Material obtained from excavation within the limits of the location and used in embankments, or for any other purpose, will be paid for as excavation only.

Allowance for culvert excavation will include only one (1) foot outside of the masonry sections, as shown on plans.

Borrow.

When, in the opinion of the engineer, there is not sufficient suitable material within the limits of the highway location of the section under contract to form the necessary embankments, or for subgrading, or for shoulders, the contractor shall obtain such material from outside the highway location. This material shall be known as borrow, and may be of any quality satisfactory to the engineer for the purpose for which it is required.

If found within a radius of one thousand (1,000) feet from any point on said section under contract it will be paid for at the borrow price.

If, however, in the opinion of the engineer, no suitable material can be obtained within the limit just described, the contractor shall find satisfactory material at a greater distance. In this event, in addition to the regular borrow price, the sum of one-half ($\frac{1}{2}$) cent per cubic yard for each one hundred (100) feet of overhaul shall be allowed him for all material so supplied, the length of haul to be measured from the pit along the shortest available route to the one thousand (1,000) foot limit above described.

Borrow pits will be cross-sectioned and all quantities will be measured in the pits.

Ledge Excavation.

Only such ledge as requires blasting for its removal, and boulders of one-half (½) a cubic yard or more in volume, will be estimated as ledge excavation.

No allowance for ledge excavation in the roadbed shall be made outside of or for more than twelve (12) inches below the lines indicated on the cross sections showing the finished surface, the side slopes to be one-fourth (¼) to one (1).

Allowance for ledge in drains will be made on the basis of a width of trench of two (2) feet and a depth of four (4) inches below the invert of the pipe; allowance for ledge in gutters will be made on the basis of the width of the gutter and twelve (12) inches in depth below the proposed surface.

Culverts.

Reinforced Portland cement concrete culverts shall be constructed where ordered by the engineer to the lines and grades given by him.

Culvert ends shall be laid parallel to the center line of the roadway. All culvert masonry shall be measured in accordance with the dimensions shown on the plans.

No allowance shall be made for cofferdams, pumps, labor, etc., which may be necessary on account of water.

Portland Cement Concrete Masonry.

The concrete shall be composed of broken stone or screened gravel, and sand—all of which shall be clean, hard, durable, sharp, and free from clay, dirt, and other objectionable material—Portland cement and fresh, clean water.

To each part of Portland cement there shall be by volume two (2) parts of sand and five (5) parts of broken stone or screened gravel, and such a proportion of water as the engineer may from time to time determine.

The broken stones or gravel stones shall be of the following sizes:

For all work less than six (6) inches in thickness the stones may vary in their longest dimension from one-quarter (¼) of an inch to three-quarters (¾) of an inch; between six (6) inches and twelve (12) inches, from one-quarter (¼) of an inch to one and one-quarter (1¼) inches; more than twelve (12) inches in thickness, from one-quarter (¼) inch to two and one-half (2½) inches.

The cement and sand shall first be thoroughly mixed dry, in the proportions specified, in proper boxes. Clean water shall then be added and the materials thoroughly mixed. The broken stone, previously drenched with water, shall then be deposited in this mixture and the ingredients thoroughly mingled and turned over until each stone is covered with mortar. The batch shall then be carefully deposited without delay and thoroughly rammed in layers not more than six (6) inches in depth until the water flushes to the surface and all the voids are filled.

The concrete shall not be allowed to fall from any considerable height.

Before the concrete is placed in the moulds, a sheet-iron plate, six or eight inches in width and about six feet long, or of such other dimensions as the contractor may find convenient, shall be held in position one and one-half (1½) inches from the surface of the mould or form. The space between the form and this separator shall be filled with mortar, composed of one part of Portland cement and one part of sand, mixed to such a consistency as the engineer may direct, and, if he shall so direct, the mortar shall be thoroughly spaded after it is placed. Only a small batch shall be mixed at a time, and then only as needed. Immediately after the space between the separator and the form is filled with mortar the ordinary concrete shall be placed behind the separator, the separator removed, and the backing and facing thoroughly rammed together to a close bond. No delay shall be permitted in placing the concrete backing, and both the facing and the backing shall be done as nearly simultaneously as is possible.

Should voids be discovered when the forms are taken down, the defective work is to be removed and the space refilled with one to one cement mortar. The exposed surfaces shall be smoothed over with a neat Portland cement grout, laid on with a brush, until a smooth surface is secured.

Centres and forms, satisfactory to the engineer, shall be provided by the contractor. They shall be made of planed lumber and shall fit the curves and shapes of the work. The sheathing shall be laid tight and shall be made clean before using.

The centres shall be true to the lines, satisfactorily supported and firmly secured, and shall remain in place as long as the engineer may direct, and shall be replaced by new ones when they lose their proper dimensions or shape.

In connecting concrete already set with new concrete, the surface shall be cleaned and roughened and mopped with a mortar composed of one part Portland cement and one part sand.

When work is done under such conditions that the mortar is liable to freeze, the contractor shall provide the necessary means for and shall thoroughly heat all materials, and also the water, and shall thoroughly protect the masonry from damage by rain and frost during and after laying.

During warm and dry weather, and whenever the engineer may direct, all newly built concrete shall be kept well shaded from the sun and well sprinkled with water until set.

In laying concrete under water the concrete shall not fall from any considerable height, but be deposited in the allotted place in a compact mass. The concrete must not be rammed, but leveled with a rake or other suitable tool immediately after being deposited. No concrete shall be laid in running water.

Expanded metal or twisted rods, to be furnished to the contractor by the commission, shall be imbedded in the concrete by the contractor as directed by the engineer, without extra compensation.

No back-filling or loading whatever shall be placed on or against the concrete masonry until ordered by the engineer.

The Massachusetts highway commission will furnish all cement to be used in this work and will deliver it to the contractor at the nearest railroad freight station. The contractor shall, at his own expense, team the cement to the work and store it, and protect it from the weather to the satisfaction of the engineer.

The price to be paid per cubic yard for concrete masonry shall include the back-filling and all necessary centres and forms, and all work on the same, and no allowance shall be made for cofferdams, pumping or bailing, or for any materials or labor necessary on account of water.

All concrete shall be measured in accordance with the dimensions shown on plans.

Shaping Surface for Broken Stone.

Before the broken stone is spread the roadbed shall be shaped to a true surface, conforming to the proposed cross section of the highway and rolled by a steam roller, unless otherwise ordered by the engineer. All depressions occurring must be filled with suitable material and again rolled, until the surface is smooth and hard, the width to be paid for to include only the width of broken stone.

Broken Stone.

Broken stone, consisting of ———, shall be spread and rolled on the roadbed prepared as hereinbefore described, as follows:

The width of the broken stones shall be ——— (—) feet.

All broken stone used shall be laid in layers or courses. The bottom course shall consist of stones from one and one-quarter (1¼) inches to two and one-half (2½) inches in their longest dimension; the upper course of stone from one-half (½) inch to one and one-quarter (1¼) inches in their longest dimension.

The bottom course shall be ——— (—) inches deep at the centre and ——— (—) inches deep at the sides after rolling. The top course shall be ——— (—) inches deep at the centre and ——— (—) inches deep at the sides after rolling.

After the two courses above described are thoroughly compacted, broken-stone screening shall be laid on, watered, and rolled until the mud flushes to the surface. The screenings so used shall not be larger than will pass through a half-inch mesh and shall contain all the dust. Care must be taken to lay on only enough of the screenings to cover the larger stones.

Each course, bottom, top, and binder, shall be rolled separately by a steam roller and evened up with material of the same size and quality as has been used in that particular course, and to the satisfaction of the engineer.

All broken stone shall be spread from the carts by hand, or from a dumping board, or from self-spreading carts.

No soft or disintegrated stone shall be used.

If so ordered by the engineer the thickness of the broken stone shall be increased or diminished at such points as he may direct.

The grade of the finished surface of the road shall present a crown of three-quarters ($\frac{3}{4}$) of an inch to the foot.

If local stone or stone not shipped by rail is used it shall be weighed on scales furnished by and at the expense of the contractor. Said scales shall be satisfactory to the engineer and they shall be sealed at the expense of the contractor as often as the engineer may deem necessary to insure their accuracy.

A sworn weigher, to be appointed and compensated by the Massachusetts highway commission, shall weigh all broken stone required to be weighed as above provided.

If the stone is shipped by rail the car weights will be accepted.

Vitrified Clay Pipe and Iron Water Pipe (for Culverts).

Vitrified clay pipe and iron water pipe shall be furnished and laid where directed by the engineer.

All clay pipe shall be of first quality, salt glazed, free from blisters and cracks, straight and round. If eighteen (18) inches or more in diameter, the pipe shall be "double strength," or if ordered by the engineer, ordinary pipe may be used and laid in concrete, which shall be tamped about the pipe to the satisfaction of the engineer. If, however, concrete is used, it shall be paid for at the regular price for concrete.

All iron pipe shall be of the best quality of water pipe and free from imperfections of any kind.

All pipe shall be laid true to the lines and grades furnished by the engineer. Nothing but selected fine material, free from large stones, shall be placed around and under the pipe, and all material placed under and about the pipe shall be thoroughly tamped in place by a thin iron tamping bar. All joints shall be made of first quality natural cement mortar, mixed in proportion of one (1) part cement to one (1) part of clean, sharp sand, carefully filled in all around the pipe. The ends of pipe drains used as culverts must be protected by concrete masonry or concrete walls. The price per foot paid for pipe laid as above includes the cost of trenching and back-filling, and all incidental work except the masonry ends; *provided, however*, that when the depth of the trench exceeds five (5) feet all excavation necessary on account of additional depth shall be paid for by the cubic yard at the regular contract price for excavation.

Guard Rail.

Fencing shall be placed on edges of embankments and at such other places along the road as the engineer may deem necessary. It shall be of the section shown on plan; the posts shall be of well-seasoned, straight, sound chestnut or cedar, not less than six (6) inches in diameter, spaced eight (8) feet apart on centres, the bottom of each post to be sawed off square and set plumb in straight lines, three (3) feet into the ground and three and one-half ($3\frac{1}{2}$) feet above the ground, and the back-filling thoroughly tamped. All bark shall be removed before setting, all knots hewn down to face and the exposed surfaces shaved. The top rails shall be four (4) inches square and the side rails of two by six (2×6) inch well-seasoned, straight-grained spruce or other wood satisfactory to the engineer, planed, free from loose or unsound knots, and both top and side rail shall be notched into and securely fastened to the posts, as shown in the plan, and be long enough to extend over three (3) posts and break joints.

All parts of the exposed surface of the fence shall be painted with one coat of white lead and linseed oil.

At culverts, square iron posts, one and one-quarter ($1\frac{1}{4}$) inches square, shall be used, set into the coping stone at least four (4) inches, and leaded. The side rail shall be bolted to the iron posts with two bolts set in holes drilled through each post.

Side Drains.

Drains will be built where directed by the engineer.

All drains must be carried to an outlet approved by the engineer.

The drain trench shall be excavated to a width of twelve (12) inches at the bottom and fifteen (15) inches at the top, and shall be excavated only as fast as the drain can be finished.

When the grade of the finished road is three (3) inches or more to the hundred (100) feet, the bottom of the drain trench must be three and one-half (3½) feet below the finished surface of the road at that part of the cross section.

On the bottom of this trench shall be placed two (2) inches of gravel or broken stone which will pass through a one and one-quarter (1¼) inch mesh, and not through a half (½) inch mesh.

On this material shall be laid a five (5) inch salt-glazed vitrified clay pipe, with bell and spigot joints, unless otherwise ordered, with open joints, and the bell ends toward the rising grade.

All pipe must be laid true to a line and grade, and no pipe is to be laid on a grade of less than three (3) inches in one hundred (100) feet.

Gravel or broken stone of the sizes already described shall be filled about the pipe and over it for a depth of one (1) foot. This must be carefully tamped about and rammed over the pipe. The remainder of the trench is to be filled with stone which will pass through a three (3) inch and not through a one (1) inch mesh, and this material shall be thoroughly tamped. Any sand, silt, or earth getting into the pipe or the interstices of the stone in the trench must be removed by the contractor at his own cost, even if it be necessary to rebuild the drain.

Where, in the opinion of the engineer, it is necessary to extend a drain to an outlet beyond the section needing to be drained, the pipe will be laid with cement joints, true to line and grade, and the gravel or stone in the trench omitted, the trench being back-filled with the material excavated from the same.

Where a pipe is carried through a bank the outlet must be protected by masonry, as provided in pipe culverts.

The price per lineal foot includes the cost of trenching and refilling with gravel or broken stone, the cost of the pipe and laying, as well as all incidental work.

No allowance will be made for pipe larger than above specified laid in any drain unless the larger pipe has been ordered in writing by the engineer.

Stone Filling.

At such places as the engineer may direct, stone filling shall be placed. Excavations shall be made to the lines shown on the cross sections. The stones may be either wall stones or cobbles ranging in size from the smallest obtainable to those not exceeding eight (8) inches in their longest dimension, and the larger stones shall be placed at the bottom.

The excavation will be paid for at the regular price for excavation.

The stone filling will be measured according to the original cross sections, without allowance for shrinkage or settlement, and paid for by the cubic yard.

Catch Basins.

Catch basins will be built of brick masonry or Portland cement concrete, as shown on plan and in accordance with the directions of the engineer.

All bricks used shall be well formed and hard burnt and shall be well soaked in water before laying.

The joints shall be thoroughly flushed full of mortar, consisting of one part of natural cement of the best quality and two parts of coarse, clean, sharp sand, free from loam and pebbles.

No joint on the face shall be greater than one-quarter inch.

After the bricks are laid the joints shall be neatly pointed on the inside.

As the walls are laid up they shall be well plastered with mortar on the outside.

The contractor is to furnish all labor, tools, and materials necessary for the basins, excepting the frames and grates, which will be furnished by the commission, and delivered at the railroad freight station nearest to the site of the work. The price paid for each basin will include all excavation, back filling, and incidental work.

Cobble-Stone Gutters.

Paved gutters will be built where directed by the engineer, the same to be laid by journeymen pavers.

No gutter is to be laid until after the broken stone has been rolled, unless otherwise ordered by the engineer.

In no case is the roller to pass over any part of any paved gutter.

Gutters not exceeding four hundred (400) feet in length shall be three (3) feet wide with a shoulder one (1) foot wide and a dish of three (3) inches.

Gutters exceeding four hundred (400) feet in length shall increase the dish above this length at the rate of one (1) inch to each three hundred (300) feet.

All stone used in gutters shall be rounded field, bank, or river stone; no flat, shaky, or rotten stone shall be used.

The stone may, on the average, lay from four (4) to six (6) square yards to the ton. A cubic yard may be estimated to weigh one and one-third ($1\frac{1}{3}$) tons.

The larger selected stone will be laid in the gutter row and on the edges to a true line and grade, with the largest diameters lengthwise of the road. All other stone will be laid with the longest diameters across the gutter.

The trench shall be excavated to a depth of twelve (12) inches below the finished grade of the gutter; gravel shall then be spread and rammed to a depth of four (4) inches. A layer of bedding sand, or gravel free from stone larger than one-half ($\frac{1}{2}$) inch in diameter, shall then be spread to a sufficient thickness to bring the gutter stone which are bedded in it to the proper grade and cross section after they are thoroughly rammed.

Each stone is to be rammed to an unyielding foundation. The contractor shall employ one rammer to every two pavers. The surface shall then be covered with coarse sand or fine-screened gravel free from clay or dirt, which must be well broomed into all joints. The stone shall then be rerammed and the surface left smooth and even. If from any cause the stone in a gutter shall have been disturbed and left uneven, they must be relaid by the contractor and at his cost. Sand or screened gravel shall then be spread over the entire surface of sufficient depth to fill all interstices.

The edge of the gutter toward the road shall be left one-quarter ($\frac{1}{4}$) inch below the surface of the adjoining broken stone; in no case must it project above it.

All broken stone which may be disturbed during the paving of the gutter must be carefully replaced and thoroughly rammed.

The bank on the outside of the gutter must be sloped to the gutter, so as to have no bunches or depressions on its surface.

COST OF MACADAMIZED ROADS IN MASSACHUSETTS.

Tables 7 to 11 show the actual costs to the Commonwealth of Massachusetts of broken stone in place on State highways completed during the year 1906; also average contract prices for other items of construction.

TABLE 7.—*Imported stone (trap rock).*[a]

City.	Length in feet.[b]	Square yards.	Number of tons.	Square yards per ton.	Cost per ton in place.	Cost per square yard in place.	Total cost of stone in place.	Cost per mile.[b]
Agawam	3,400	5,667	1,702.67	3.33	$2.10	$0.6309	$3,575.61	$5,552.00
Bedford	2,798	4,663	1,523.40	3.06	2.15	.7024	3,275.31	6,180.00
Chicopee	2,100	3,500	1,175.00	2.98	2.30	.7721	2,702.50	6,788.00
Concord	3,334	5,557	1,627.50	3.41	1.85	.5418	3,010.87	4,768.00
Deerfield	2,222	3,703	1,202.20	3.08	1.70	.5519	2,043.74	4,856.00
East Longmeadow	2,409	4,015	1,295.50	3.00	1.80	.5808	2,331.90	5,111.00
Granby	2,677	4,461	1,516.00	2.94	2.25	.7646	3,411.00	6,728.00
Greenfield	2,350	3,917	1,130.90	3.46	1.75	.5053	1,979.08	4,447.00
Groveland	1,493	2,488	839.80	2.96	1.925	.6480	1,616.61	5,702.00
Hatfield	1,750	2,917	968.50	3.01	1.75	.5810	1,694.87	5,113.00
North Brookfield	2,750	4,583	1,475.85	3.10	2.00	.6441	2,951.70	5,668.00
Pittsfield	2,560	4,267	1,276.25	3.26	1.90	.5683	2,424.87	5,001.00
Sunderland	1,200	2,000	695.26	2.88	2.00	.6953	1,390.52	6,119.00
Tewksbury	3,924	6,540	2,328.00	2.81	2.20	.7831	5,121.60	6,891.00
West Springfield	4,000	6,667	1,884.55	3.54	1.70	.4805	3,203.74	4,228.00
Whately, 1905	3,423	5,704	1,854.52	3.07	1.75	.5689	3,245.41	5,006.00
Whately, 1906	1,178	1,964	684.75	2.87	2.00	.6971	1,369.50	6,134.00
Totals and averages	[c]43,568	[c]72,613	[c]23,180.65	[d]3.13	[d]1.956	[d].6245	[c]45,348.83	[d]5,496.00

[a] Six inches in depth at center; 4 inches in depth at sides.
[b] Equated to basis of road 15 feet wide.
[c] Total.
[d] Average.

TABLE 8.—*Imported stone (trap rock).*[a]

City.	Length in feet.[b]	Square yards.	Number of tons.	Square yards per ton.	Cost per ton in place.	Cost per square yard in place.	Total cost of stone in place.	Cost per mile.[b]
Chatham	5,217	8,695	2,208.47	3.94	$1.95	$0.4953	$4,306.52	$4,359.00
Concord	5,114	8,523	2,491.40	3.42	1.793	.5241	4,466.83	4,611.00
Dennis	4,353	7,255	1,956.03	3.71	2.20	.5930	4,303.27	5,218.00
Falmouth	1,855	3,093	801.60	3.86	2.75	.7127	2,204.40	6,272.00
Grafton	2,640	4,400	1,173.35	3.74	2.00	.5333	2,346.70	4,693.00
Huntington	2,421	4,035	1,071.00	3.78	1.90	.5043	2,034.90	4,438.00
Kingston	5,366	8,943	2,367.60	3.78	2.05	.5427	4,853.58	4,776.00
Templeton	3,100	5,167	1,437.70	3.59	1.93	.5370	2,774.76	4,726.00
Wareham	6,752	11,254	2,832.40	3.97	2.05	.5159	5,806.42	4,540.00
Totals and averages	[c]36,818	[c]61,365	[c]16,339.55	[d]3.76	[d]2.025	[d].5393	[c]33,097.38	[d]4,746.00

[a] Four inches in depth throughout.
[b] Equated to basis of road 15 feet wide.
[c] Total.
[d] Average.

TABLE 9.—*Local stone.*[a]

City.	Length in feet.[b]	Square yards.	Number of tons.	Square yards per ton.	Cost per ton in place.	Cost per square yard in place.	Total cost of stone in place.	Cost per mile.[b]
Auburn	7,686	12,810	4,119.00	3.11	$1.41	$0.4534	$5,807.79	$3,990.00
Bellingham	1,208	2,018	650.00	3.10	1.65	.5327	1,072.50	4,688.00
Bellingham, 1905	3,855	6,425	2,020.00	3.18	1.30	.4087	2,626.00	3,597.00
Bellingham, 1906	4,870	8,117	2,511.44	3.23	1.30	.4022	3,264.87	3,539.00
Berkley	4,045	6,742	1,993.37	3.38	1.35	.3991	2,691.05	3,512.00
Beverly	4,861	8,102	2,206.45	3.67	1.55	.4221	3,420.00	3,714.00
Bridgewater	3,300	5,500	1,455.50	3.78	1.35	.3572	1,964.92	3,143.00
Burlington	5,160	8,600	2,522.45	3.41	1.45	.4253	3,657.55	3,743.00
Charlton	2,792	4,653	1,538.50	2.99	1.45	.4794	2,230.82	4,219.00
Douglas	2,822	4,704	1,408.00	3.34	1.48	.4429	2,083.84	3,898.00
Dracut	6,500	10,833	3,454.80	3.14	1.44	.4592	4,974.91	4,041.00
Dighton	2,915	4,858	1,781.66	2.73	1.50	.5501	2,672.50	4,841.00
Framingham	6,737	11,228	2,714.67	4.14	1.157	.2800	3,142.17	2,464.00
Gloucester	2,883	4,805	1,440.00	3.34	1.70	.5094	2,448.00	4,483.00
Hudson	4,039	6,732	2,046.49	3.29	1.44	.4377	2,946.95	3,852.00
Melrose-Saugus	3,100	5,167	1,543.28	3.35	1.25	.3733	1,929.10	3,285.00
Middleboro	3,807	6,345	1,892.88	3.35	1.25	.3729	2,366.10	3,281.00
Millbury	3,100	5,167	1,692.68	3.05	1.40	.4586	2,369.75	4,036.00
Montague	3,958	6,597	2,032.80	3.24	1.55	.4776	3,150.84	4,203.00
Norton	2,650	4,416	1,300.00	3.39	1.65	.5006	2,145.00	4,405.00
Oxford	4,482	7,470	2,349.00	3.18	1.374	.4325	3,229.74	3,806.00
Rehoboth	3,473	5,788	1,580.00	3.66	1.25	.3412	1,975.00	3,002.00
Southboro	5,985	9,975	3,437.00	2.90	1.30	.4479	4,468.10	3,942.00
Stoughton	7,006	11,677	3,445.02	3.39	1.40	.4130	4,823.03	3,634.00
Swansea	7,612	12,687	3,087.30	4.11	1.25	.3042	3,859.12	2,677.00
W. Newbury, 1905	3,936	6,558	2,178.29	3.01	1.49	.4949	3,245.65	4,355.00
W. Newbury, 1906	2,000	3,333	1,158.83	2.88	1.55	.5387	1,795.41	4,741.00
Totals and averages	[c]114,782	[c]191,307	[c]57,558.91	[d]3.32	[d]1.396	[d].4201	[c]80,360.71	[d]3,696.00

[a] Six inches in depth at center; 4 inches in depth at sides.
[b] Equated to basis of road 15 feet wide.
[c] Total.
[d] Average.

TABLE 10.—*Local stone.*[a]

City.	Length in feet.[b]	Square yards.	Number of tons.	Square yards per ton.	Cost per ton in place.	Cost per square yard in place.	Total cost of stone in place.	Cost per mile.[b]
Canton, 1905	3,000	5,000	1,221.30	4.09	$1.54	$0.3762	$1,880.80	$3,310.00
Canton, 1906	4,450	7,417	1,955.84	3.79	1.55	.4087	3,031.55	3,596.00
Chilmark	7,042	11,736	2,960.90	3.80	1.80	.4572	5,365.62	4,023.00
Gloucester	1,733	2,889	728.00	3.97	1.70	.4284	1,237.60	3,770.00
Lancaster-Sterling	5,245	8,743	2,173.28	4.01	1.50	.3728	3,259.92	3,280.00
Needham	5,490	9,150	2,366.79	3.86	1.40	.3621	3,313.51	3,186.00
Rockland	2,329	3,882	1,065.73	3.64	1.75	.4804	1,865.03	4,228.00
Wareham	5,362	8,937	1,845.33	4.84	1.49	.3079	2,749.54	2,709.00
Totals and averages.	[c]34,651	[c]57,754	[c]14,337.17	[d]4.03	[d]1.583	[d].3931	[c]22,703.57	[d]3,459.00

[a] Four inches in depth throughout.
[b] Equated to basis of road 15 feet wide.
[c] Total.
[d] Average.

TABLE 11.—*Averages of contract prices for the several construction items, exclusive of macadam.*

Excavation	per cubic yard	$0.4352
Borrow	do	.5622
Ledge excavation	do	1.78
Cement concrete masonry	do	[a]8.85
Shaping road for broken stone	per square yard	.0281
Vitrified 12-inch clay pipe, in place	per linear foot	.7662
Vitrified 10-inch clay pipe, in place	per linear foot	$0.6430
Vitrified 8-inch clay pipe, in place	do	.57
Vitrified 18-inch clay pipe, in place	do	1.57
12-inch iron water pipe, in place	do	2.20
18-inch iron water pipe, in place	do	3.75
Stone filling for V-drains, in place	per cubic yard	.8271
Guard rail, in place	per linear foot	.2770
Catch-basins, in place (including catch-basin frames and grates)	each	35.74
Setting stone bounds	do	1.85

COST OF STATE-AID ROADS IN NEW JERSEY.

Tables 12 to 14 give the costs of State-aid roads in New Jersey in 1905, as shown in the Report of the Commissioner of Public Roads of that State for 1905 (pp. 85–87):

TABLE 12.—*Stone bed 4 inches deep.*

Width of stone.	Length.	Length of road if 15 feet wide.	Area.	Unit price per square yard.	Total cost.	Cost per mile of road 15 feet wide.
Feet.	*Feet.*	*Feet.*	*Sq. yards.*			
28	2,287	4,202	7,136	$0.3500	$2,497.74	$3,080.00
28	5,078	9,479	15,610	.3300	5,151.30	2,904.00
16	5,572	5,943	10,398	.1800	1,871.64	1,584.00
14	15,415	14,387	23,979	.1800	4,316.22	1,584.00
	[b]28,352	[b]34,011	[b]57,123	[c].2422	[b]13,836.90	[c]2,148.00

[a] This price does not include the cement or the steel reinforcement, which may be estimated at about $3 additional.
[b] Total.
[c] Average.

TABLE 13.—*Stone bed 6 inches deep.*

Width of stone.	Length.	Length of road if 15 feet wide.	Area.	Unit price per square yard.	Total cost.	Cost per mile of road 15 feet wide.
Feet.	*Feet.*	*Feet.*	*Sq. yards.*			
14	12,195	11,382	19,222	$0.6000	$11,533.20	$5,280.00
14	5,361	5,004	9,105	.6100	5,554.05	5,368.00
16	3,335	3,557	5,986	.7000	4,190.20	6,160.00
14	8,050	7,513	12,522	.6700	8,389.74	5,896.00
14	10,910	10,183	16,971	.6200	10,522.02	5,456.00
	a 39,851	a 37,639	a 63,806	b .6299	a 40,189.21	b 5,637.00

[a] Total. [b] Average.

TABLE 14.—*Stone bed 8 inches deep.*

Width of stone.	Length.	Length of road if 15 feet wide.	Area.	Unit price per square yard.	Total cost.	Cost per mile of road 15 feet wide.
Feet.	*Feet.*	*Feet.*	*Sq. yards.*			
12	7,385	5,908	9,847	$1.0000	$9,847.00	$8,800.00
14	5,393	4,981	8,244	.6128	5,052.26	5,393.00
14	14,665	13,687	23,193	.7200	16,698.96	6,336.00
16	20,949	22,346	38,208	.60	23,057.00	5,280.00
14	9,940	9,277	15,623	.70	11,076.50	6,160.00
14	16,608	15,501	26,237	.74	19,519.08	6,512.00
12	5,280	4,224	7,040	.5749	4,047.20	5,059.00
12	7,410	5,928	9,880	.6593	6,513.40	5,802.00
12	7,448	5,958	9,930	.67	6,652.83	5,896.00
14	7,720	7,205	12,090	.75	9,067.20	6,600.00
14	16,400	15,307	25,511	.73	18,623.03	6,424.00
12	5,700	4,560	7,600	.58	4,408.00	5,104.00
	a 124,898	a 114,882	a 193,403	b .6958	a 134,562.46	b 6,187.00

[a] Total. [b] Average.

SKETCHES OF STANDARD DETAILS.

[Massachusetts State roads.]

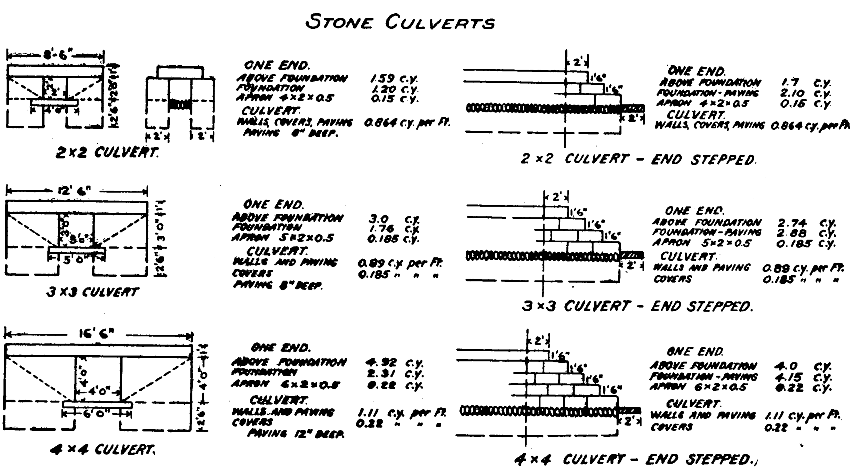

FIG. 3.

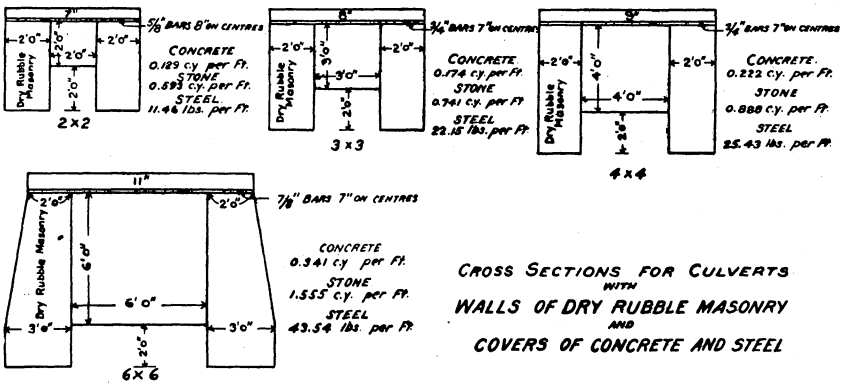

FIG. 4.

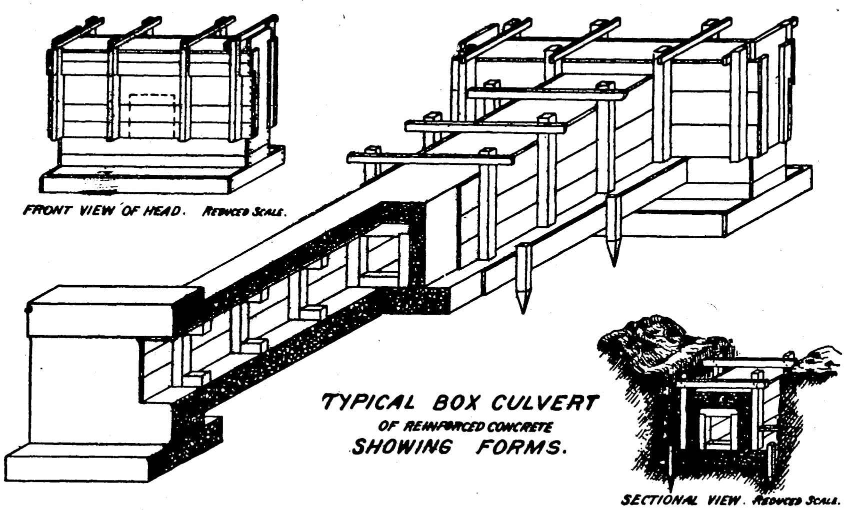

FIG. 5.

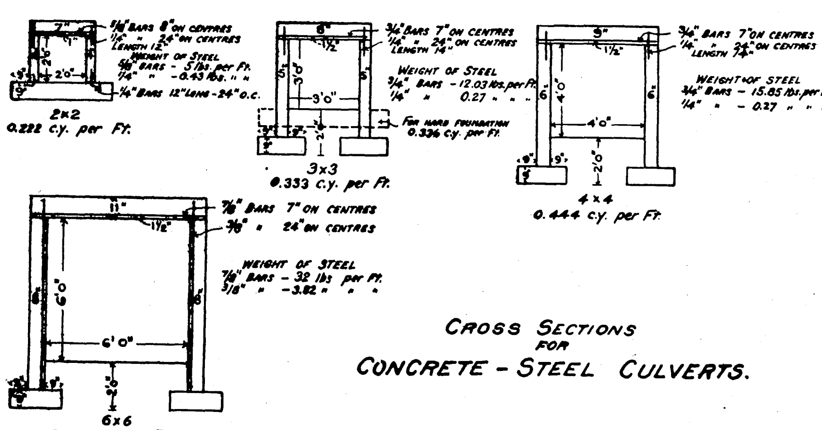

FIG 6

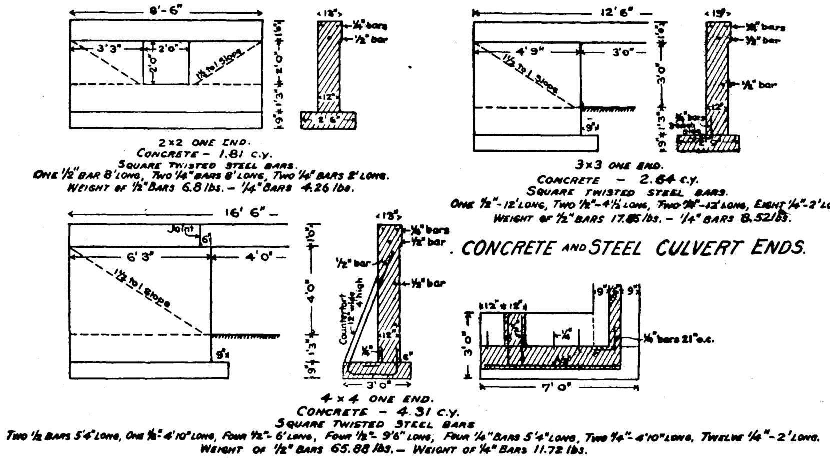
2×2 ONE END.
CONCRETE – 1.81 C.Y.
SQUARE TWISTED STEEL BARS.
ONE 1/2" BAR 8' LONG, TWO 1/4" BARS 8' LONG, TWO 1/4" BARS 2' LONG.
WEIGHT OF 1/2" BARS 6.8 lbs. – 1/4" BARS 4.26 lbs.
3×3 ONE END.
CONCRETE – 2.64 C.Y.
SQUARE TWISTED STEEL BARS.
ONE 1/2"-12' LONG, TWO 1/2"-4 1/2' LONG, EIGHT 1/4"-2' LONG.
WEIGHT OF 1/2" BARS 17.85 lbs. – 1/4" BARS 8.52 lbs.
CONCRETE AND STEEL CULVERT ENDS.
4×4 ONE END.
CONCRETE – 4.31 C.Y.
SQUARE TWISTED STEEL BARS
TWO 1/2 BARS 5'4" LONG, ONE 1/2"-4'10" LONG, FOUR 1/2"-6' LONG, FOUR 1/2"-9'6" LONG, FOUR 1/4" BARS 5'4" LONG, TWO 1/4"-4'10" LONG, TWELVE 1/4"-2' LONG.
WEIGHT OF 1/2" BARS 65.88 lbs. – WEIGHT OF 1/4" BARS 11.72 lbs.

FIG. 7.

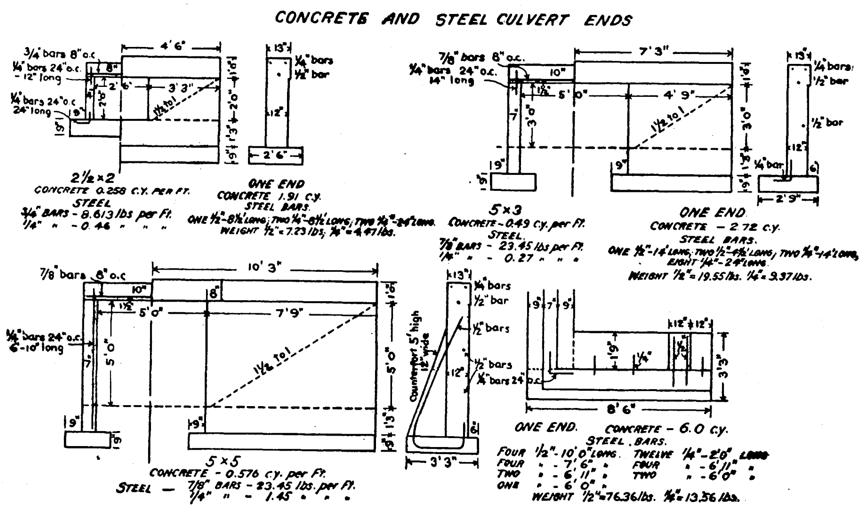
CONCRETE AND STEEL CULVERT ENDS
2 1/2×2
CONCRETE 0.258 C.Y. PER FT.
STEEL
3/4" BARS – 8.613 lbs per Ft.
1/4" " – 0.46 " " "
ONE END
CONCRETE 1.91 C.Y.
STEEL BARS.
WEIGHT 1/2" = 7.23 lbs; 1/4" = 4.47 lbs.
5×3
CONCRETE – 0.49 C.Y. per Ft.
STEEL.
7/8" BARS – 23.45 lbs per Ft.
1/4" " – 0.27 " " "
ONE END
CONCRETE – 2.72 C.Y.
STEEL BARS.
ONE 1/2"-14' LONG, TWO 1/2"-4 1/2' LONG, TWO 7/8"-14' LONG,
EIGHT 1/4"-24" LONG.
WEIGHT 1/2" = 19.55 lbs. 1/4" = 9.37 lbs.
5×5
CONCRETE – 0.576 C.Y. per Ft.
STEEL – 7/8" BARS – 23.45 lbs. per Ft.
1/4" " – 1.45 " " "
ONE END. CONCRETE – 6.0 C.Y.
STEEL BARS.
FOUR 1/2"-10'0" LONG. TWELVE 1/4"-2'0"
FOUR " – 7'6" " FOUR " – 6'11" "
TWO " – 6'11" " TWO " – 6'0" "
ONE " – 6'0" "
WEIGHT 1/2" = 76.36 lbs. 1/4" = 13.56 lbs.

FIG. 8.

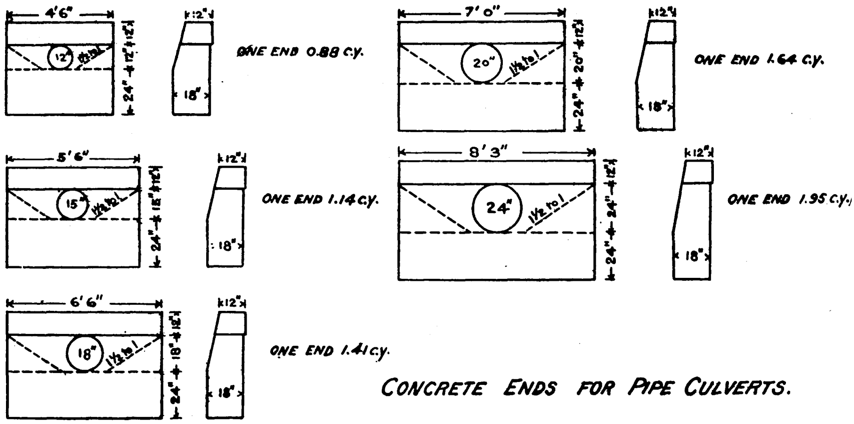
4'6"
12"
24"
12"
12"
18"
ONE END 0.88 C.Y.
7' 0"
20"
1½ to 1
24"
20"
12"
12"
18"
ONE END 1.64 C.Y.
5' 6"
15"
1½ to 1
24"
15"
12"
12"
18"
ONE END 1.14 C.Y.
8' 3"
24"
1½ to 1
24"
24"
12"
12"
18"
ONE END 1.95 C.Y.
6' 6"
18"
1½ to 1
24"
18"
12"
12"
18"
ONE END 1.41 C.Y.
CONCRETE ENDS FOR PIPE CULVERTS.

FIG. 9.

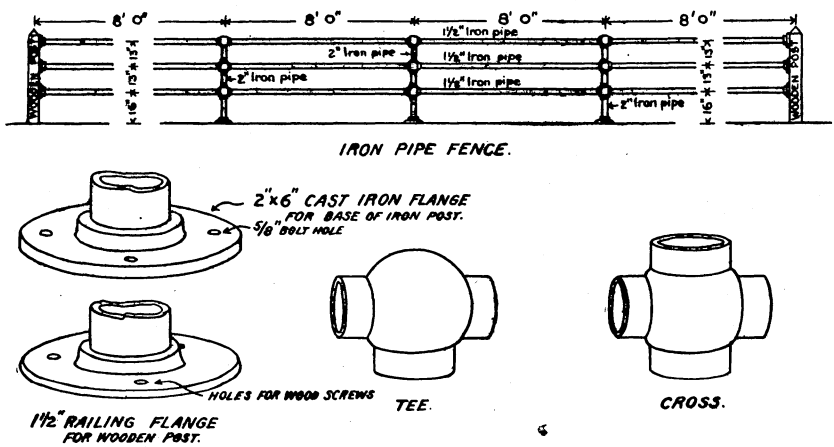
8' 0"
8' 0"
8' 0"
8' 0"
1½" Iron pipe
2" Iron pipe
1½" Iron pipe
2" Iron pipe
1½" Iron pipe
2" Iron pipe
WOODEN POST
WOODEN POST
16"
15"
15"
IRON PIPE FENCE.
2"x6" CAST IRON FLANGE FOR BASE OF IRON POST.
5/8" BOLT HOLE
HOLES FOR WOOD SCREWS
1½" RAILING FLANGE FOR WOODEN POST.
TEE.
CROSS.

FIG. 10.

O